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date: July 14, 1971

to: Distribution

from: E. N. Shipley

B71 07015

subject: Use of the Planet Mars as a Photometric Calibration Source for the Mariner '71 TV Camera -- Case 235

ABSTRACT

Mars itself can be used as a photometric target, calibrated from earth observations, for the calibration of the Mariner '71 television camera in orbit about Mars. Since the photometric function of Mars is not known, observations from earth and the spacecraft must have identical geometry. Reflection of the viewing direction in the plane defined by the sun and local vertical provides two separate viewing directions with the same illumination geometry. Places and times on Mars can be chosen so that one of the viewing directions points to the earth and the other to the spacecraft. Details of these opportunities are presented. The method is applicable to other missions and other planets.

(NASA-CR-119671) USE OF THE PLANET MARS AS A PHOTOMETRIC CALIBRATION SOURCE FOR THE MARINER 1971 TV CAMERA (Bellcomm, Inc.) 24 p

N79-72069

Unclas
00/14 12867

(ACCESSION NUMBER) (THRU)
24 (PAGES)
(CODE)
CR-119671 (NASA CR OR TMX OR AD NUMBER)
(CATEGORY)
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MEMORANDUM FOR FILE

I. INTRODUCTION

One of the problems facing the Mariner '71 mission is the verification of the calibration of the cameras during the operational part of the mission. The cameras have been intensively calibrated on the ground, but experience indicates that television systems are subject to substantial changes in their photometric properties in the course of time. Consequently, it is necessary to have some means of evaluating the photometric performance of the camera when it is operating in orbit about Mars.

The purpose of this memorandum is to show that it is possible to use Mars itself as an absolute brightness source. The brightness of various regions on Mars can be determined by earth-based observations,* and these regions, in turn, can be used to calibrate the camera. Mariner '71 operations occur after the opposition (August 12, 1971) at a time when the planetary disc is decreasing in size. Fortunately, Mars is at nearly its closest possible distance during the 1971 opposition and the size of the Martian disc is sufficiently great for useful measurements for a longer than average time past the opposition. At the end of November, 1971, the disc is 10" (10 seconds of arc) in diameter, and at the end of December, 8". For the purpose of comparison, during the 1971 opposition itself, Mars has a diameter of 25"; for those oppositions at which Mars is farthest

*Two methods are available. T. McCord has developed a technique for comparing a spot on Mars to a stellar reference. He believes that the absolute accuracy, which is limited by knowledge of the stellar source, is about 5%. B. A. Smith has suggested using a photoelectric detector to measure the integral brightness of Mars, and simultaneous photographs to measure the relative brightness of various regions. He also has indicated that 5% absolute accuracy is feasible.

from the earth, the diameter of Mars is 14". For a disc of diameter 10", an earth based resolution of 1" corresponds to about 12 degrees of arc at the center of the disc.

In using Mars as a calibration source, it is important to consider the geometry since the brightness on Mars depends on the viewing and lighting geometry. We will use the term "illumination geometry" to indicate the complete set of geometric conditions that affect the surface brightness. The photometric function on Mars is not well known and it may vary from region to region. Consequently, for a given point, the brightness in one direction cannot be reliably deduced from knowledge of the brightness under other geometric conditions. For the most accurate comparison between spacecraft and earth observations, the spacecraft and an earth-based observer should observe the same point on Mars, at the same time, with the same illumination geometry. This can be accomplished when (and if) the orbital path of the spacecraft intersects the line of sight from earth to a point on Mars. If the TV cameras on the spacecraft are oriented to look along the earth-Mars line of sight, both the spacecraft and the earth observer will see the same point on Mars, under identical conditions, at the same time. We will define this situation to be a <u>direct</u> calibration geometry.

In order to have a field of view comparable to the earth-based resolution, the spacecraft pictures should be taken with the A, or wide-angle camera. For a range to the target point of 4000 km, the diameter field of view is about 1000 km on the surface, for near-vertical viewing. This corresponds to about 15 degrees of arc on the surface.

The illumination geometry is identical for the spacecraft and earth only for the one point that lies along the earth-Mars line-of-sight. Because of the wide field of view of the spacecraft camera, the camera viewing direction may diverge up to 9° from the earth-Mars line-of-sight. This problem, which is illustrated in Figure 1, is inevitable when one views the same area from both near and far. This problem represents a limitation to the accuracy of the earth-spacecraft comparison. Corrections could be applied if the Martian photometric function were known.

Unfortunately, the orbit that has been chosen for Mariner '71 does not provide opportunities for direct calibration during the early part of the mission.* The first opportunities

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*The parameters of the orbit for which calculations have been made are given in Table I.

are available during February but they involve points near the edge of the Martian disc as seen from earth. It will be shown in Section III that this is an undesirable geometry.

It is appropriate, then, to seek situations, other than the direct calibration geometry, for which the illumination geometry is the same as seen from earth and the spacecraft. The illumination geometry can be defined by three angles, the illumination angle, i, the emission angle, ε, and the phase angle, γ. These are shown in Figure 2. Inherent in this definition is the assumption that the surface has azimuthal symmetry about its local vertical, since our definition of the illumination geometry contains no azimuthal angle.

It is not a priori necessary to restrict the possible geometries to those cases in which the spacecraft and the earth observe the same spot at the same time. However, diurnal brightness variations are known to occur on Mars, so that it is desirable to consider only those cases in which the spacecraft and the earth-based observations can be made simultaneously.

Mirror reflections in any plane passing through the local vertical will create a new illumination geometry in which the phase, illumination and emission angles are preserved. Most such reflections do not provide realizable geometries because they imply a rotation of the sun vector about the local vertical without a change in its elevation. However, the locus of the sun during the day is well defined. For a given illumination angle, there are only two possible azimuths for the sun vector, one in the morning and one in the afternoon.

However, if the reflection plane passes through the sun direction and the local vertical, the solar vector is unchanged by the reflection. This is the basis of the alternate viewing geometry, and is shown in Figure 3. In this geometry, there are two directions from which the same surface point can be viewed; both directions have the same illumination geometry, and since the vector to the sun has not been changed, correspond to simultaneous observations of the point. The alternate viewing geometry is used by choosing places and times such that one of the viewing directions points at the earth and the other at the spacecraft.

The reflected brightness seen along the two viewing directions will be the same only if the surface has azimuthal symmetry. The chaotic terrain regions on Mars show a north-easterly grain[1] and hence lack the required symmetry. Other regions may also not have azimuthal symmetry, and all such areas should be avoided for purposes of the alternate calibration geometry. Cratered terrain, on the other hand, appears to have azimuthal symmetry. For any point, the distribution of craters is the same in all directions.

The reciprocity principle[2] can also be used to generate situations in which the brightness observed by the spacecraft can be determined from earth-based observations without knowledge of the Martian photometric function. The reciprocity principle involves interchanging the illumination and emission directions, and so cannot provide opportunities unless the time of observation may be different for the spacecraft and earth.

The remainder of this memorandum is devoted to the alternate calibration geometry described above. Section II contains a description of a process by which suitable opportunities for using the geometry can be identified. Section III contains results for the proposed Mariner '71 orbit.

II. TECHNIQUE FOR CALCULATION

Consider a specific point on the surface of Mars at a given sun position (local time). The direction of the vectors to the sun and to the earth, and the direction of the local vertical are known. The vector to earth is chosen to be one of the two viewing directions of the alternate calibration geometry. It is necessary to determine the direction of the other vector. The situation is shown in Figure 4.

The vector $\vec{P}$ is a unit vector along the local vertical of the viewed point, $\vec{S}$ is a unit vector toward the sun, and $\vec{E}$ is a unit vector pointing toward the earth. These three vectors are known a priori; we wish to find the unit vector $\vec{A}$, the alternate viewing direction that gives the same illumination geometry as that of an observer at earth.

It is convenient to define an operator U that converts a vector of arbitrary length into a unit vector in its original direction. That is, $U(\vec{r})$ is a unit vector in the direction $\vec{r}$. First, we define the vector $\vec{G}$ to be a unit vector normal to the sun-local vertical plane.

$$\vec{G} = U(\vec{S} \times \vec{P}) \tag{1}$$

The unit vector $\vec{H}$ is chosen to be normal to $\vec{G}$ and to $\vec{E}$

$$\vec{H} = U(\vec{G} \times \vec{E}) \tag{2}$$

$\vec{H}$ lies in the sun-local vertical plane.

The vector $\vec{T}$ is the projection of $\vec{E}$ onto the sun-local vertical plane. Consequently, it lies in the plane defined by $\vec{G}$ and $\vec{E}$, and thus is normal to $\vec{H}$. Because it lies in the sun local vertical plane, it is also normal to $\vec{G}$. Thus the direction of T is given by $\vec{H} \times \vec{G}$

$$\vec{T} = \left[\vec{E} \cdot U(\vec{H} \times \vec{G})\right] U(\vec{H} \times \vec{G}) \tag{3}$$

Finally, since E and A are symmetric in the sun-local vertical plane

$$\vec{E} + \vec{A} = 2\vec{T}$$

and

$$\vec{A} = 2\vec{T} - \vec{E} \tag{4}$$

Once $\vec{A}$ has been found, the question remains whether or not that direction intersects the orbital path of the spacecraft. In general, it will not, and it is necessary to search for those particular points on the surface of Mars for which $\vec{A}$ does intersect the path of the spacecraft.

For the purpose of this search, points on Mars are described by their local time and their latitude. The actual longitude of a point is not included. As the planet rotates, the longitude corresponding to a given local time will vary continuously. Similarly, we ask only if the alternate viewing direction intersects the orbital path of the spacecraft; we need not be concerned with the actual location of the spacecraft at any specific time. At some time, the spacecraft will pass through the point of intersection of the alternate viewing direction and the orbit track. At that time, if the spacecraft takes a picture of the surface point with the specified local time and latitude, the illumination geometry seen from the spacecraft will be identical to that seen from earth. The actual physical location of the point, that is, its longitude, will depend on the phasing of the spacecraft trajectory with respect to the planet.

In carrying out the search, the assumption is made that the location of the sun, the location of the earth, and the orbital path, all measured in the Martian planetocentric coordinate system, do not change significantly in the time required for the spacecraft to complete a single revolution about the planet. The planetocentric longitudes of the sub-earth and sub-solar points each change by about 0.5° per day due to the motion of Mars and the earth about the sun. The orbit of the spacecraft precesses because the gravitational field of Mars is not precisely spherically symmetric. However, all of these effects are sufficiently small that good accuracy can be obtained by assuming that the solar and earth positions, and the orbital path are constant for a time equal to the orbital period of the spacecraft.

III. RESULTS

Through the use of the technique described in the previous section, alternate calibration geometries have been calculated for a possible orbit for Mariner '71. The orbital parameters that have been used are listed in Table I. Uncertainties in the final course correction and in the injection maneuver, as well as changes in the strategy for trimming the orbit, will undoubtedly cause the achieved parameters to differ slightly from those given in Table I. Such changes in the orbital parameters would affect the details but not the general character of the results.

The points of Mars which can be used with the alternate calibration geometry are shown in Figure 5. The curves have been calculated for the three days, November 25, 1971; December 25, 1971; and January 24, 1972, to indicate the trend of the data during the course of the mission. The curves are shown only for those points corresponding to the illuminated portion of the Martian disc visible from earth. In general, the left-hand termination of the curve marks the morning terminator, and the right-hand edge corresponds to points on the illuminated limb of the planet.

Figure 6 shows the possible calibration points for February, 1972, for both the direct and the alternate calibration geometries. The direct calibration points lie near the edge of the disc; the smallest emission angle is 58°. As explained below, such large emission angles are undesirable. The quality of the direct calibration geometry improves as the precession of the orbit brings the spacecraft track over more central portions of the planet, as seen from earth. This occurs too late in the mission to be of any practical use for calibration.

The illumination and emission angles for the alternate geometry are given for November 25, December 25, and January 24, in Figures 7, 8, and 9, respectively. It is desirable to have both these angles as close to zero as possible. Surface illumination depends on the cosine of the illumination angle. The illumination has, then, a broad maximum around an illumination angle of zero, and the surface brightness varies least with distance along the surface. This is desirable since it minimizes errors due to the spacecraft and the observer not viewing precisely the same region.

Because of the resolution of earth-based observations, the region seen from earth cannot be defined to better than a few hundred kilometers. If this region has all the same brightness, there is no problems if the spacecraft and earth do not look at precisely the same region. For the same reason, of course, regions with no or with small albedo variations are much to be preferred as calibration areas.

At any point viewed simultaneously by the spacecraft and earth, the illumination angle must be the same. The viewing angle, however, is the same only at the center of the field of view of the spacecraft camera. This problem arises because of the different viewing distance from earth and the spacecraft, and was illustrated in Figure 1. It is reasonable to assume that the change in the photometric function with emission angle is least for small emission angles. Furthermore, any atmospheric effects, such as haze and dust, depend on the emission angle, and are minimal at emission angles of zero. Both of these arguments indicate the difference in the apparent brightness seen from earth and from the spacecraft are minimized for emission angles near 0°.

Figure 10 shows, for each of the three days used previously, the true anomaly at which the picture is taken from the spacecraft to achieve the alternate calibration geometry. The right-hand scale on the same figure shows the time before periapsis at which the picture must be taken.

The range from the spacecraft to the surface calibration point is shown in Figure 11. The larger ranges are preferable since they lessen the difference between earth and spacecraft geometry (see Figure 1) and they increase the surface area included in a single frame. The latter factor makes the size of the earth-based resolution element less critical.

IV. CONCLUSIONS

The alternate calibration geometry provides useful opportunities to use the planet Mars as an absolute photometric calibration source for the Mariner '71 TV camera. Mars itself is calibrated using earth-based observations. The region of Mars that are is chosen for calibration use should have the following properties:

1. they must be accessible to alternate calibration geometry;
2. they should have little or no albedo variation;
3. they should be devoid of topographic features with a directional bias;
4. they should be chosen to have emission and illumination angles as chose to zero as possible within the previous constraints.

Although the application of the alternate viewing geometry to the Mariner '71 mission has been stressed in this memorandum, the technique is also applicable to other missions and to other planets. Its use for the '71 mission is made more practical because of the unusually large size of Mars, as seen from earth, during the 1971 opposition. Its use in other applications depends primarily on the ability of spacecraft to photograph, with reasonable geometry, a region corresponding to at least one resolution element as seen from earth.

For a planet that does not have substantial diurnal variations, additional geometries that do not restrict the observation from the spacecraft and earth to the same time of day are available. These are four identical illumination geometries for a given point. These involve the sun vector in the morning and in the afternoon at the same illumination angle; for each sun position the viewing direction can be reflected in the sun-local vertical plane. Further opportunities are available through use of the reciprocity principle.

E. N. Shipley

1011-ENS-pjr

E. N. Shipley

Attachments
References
Table I
Figures 1-11

REFERENCES

1. Sharp, Soderblom, Murray and Cutts, Jour. Geophys. Res. 76. 331 (1971).

2. Chandrasekhar, S., Radiative Transfer, Dover Publications, New York (1960), pp. 20-21.

TABLE 1

Orbital Parameters Used in the Calculation

Arrival Date	November 14, 1971
Period	12.0 hr
Periapsis Altitude	1250. km
Psi	136.0°
Inclination	65.0°

Initial Euler Angles for the Orbit

Angle from x axis to line of nodes, Ω_n	32.83°
Inclination, angle from z axis to the normal to the orbit plane, i	65.00°
Angle from line of nodes to the line of apsides (periapsis), Ω_p	-22.87°

Precession Rates

$\dot{\Omega}_n$	-.090036°/orbit
$\dot{\Omega}_p$	-.011394°/orbit

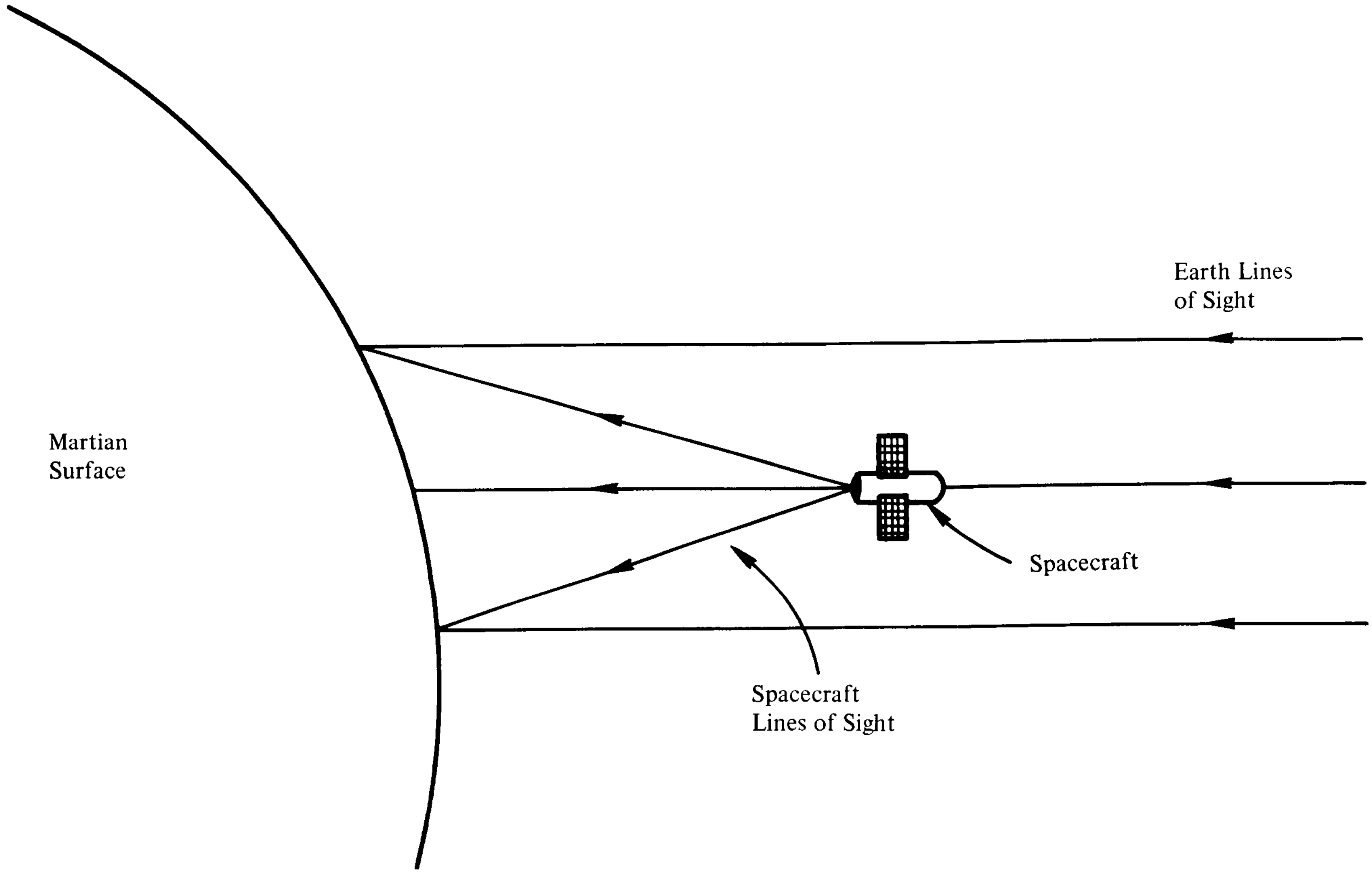
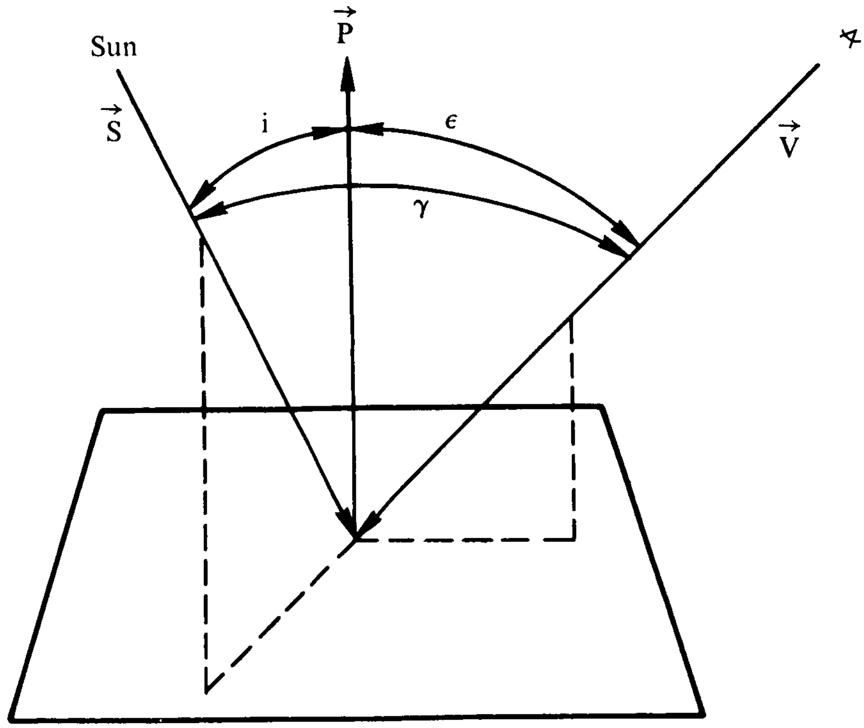


FIGURE 1 - DIFFERENCE IN VIEWING GEOMETRY OF MARS FOR EARTH AND A MARS-ORBITING SPACECRAFT



γ: Phase Angle

ϵ: Emission (Viewing) Angle

i: Illumination (Lighting) Angle

$\vec{P}$: Local Vertical

$\vec{S}$: Unit Vector Along Sun Direction

$\vec{V}$: Unit Vector Along Observation Direction

FIGURE 2 - ANGLES THAT DEFINE THE ILLUMINATION GEOMETRY

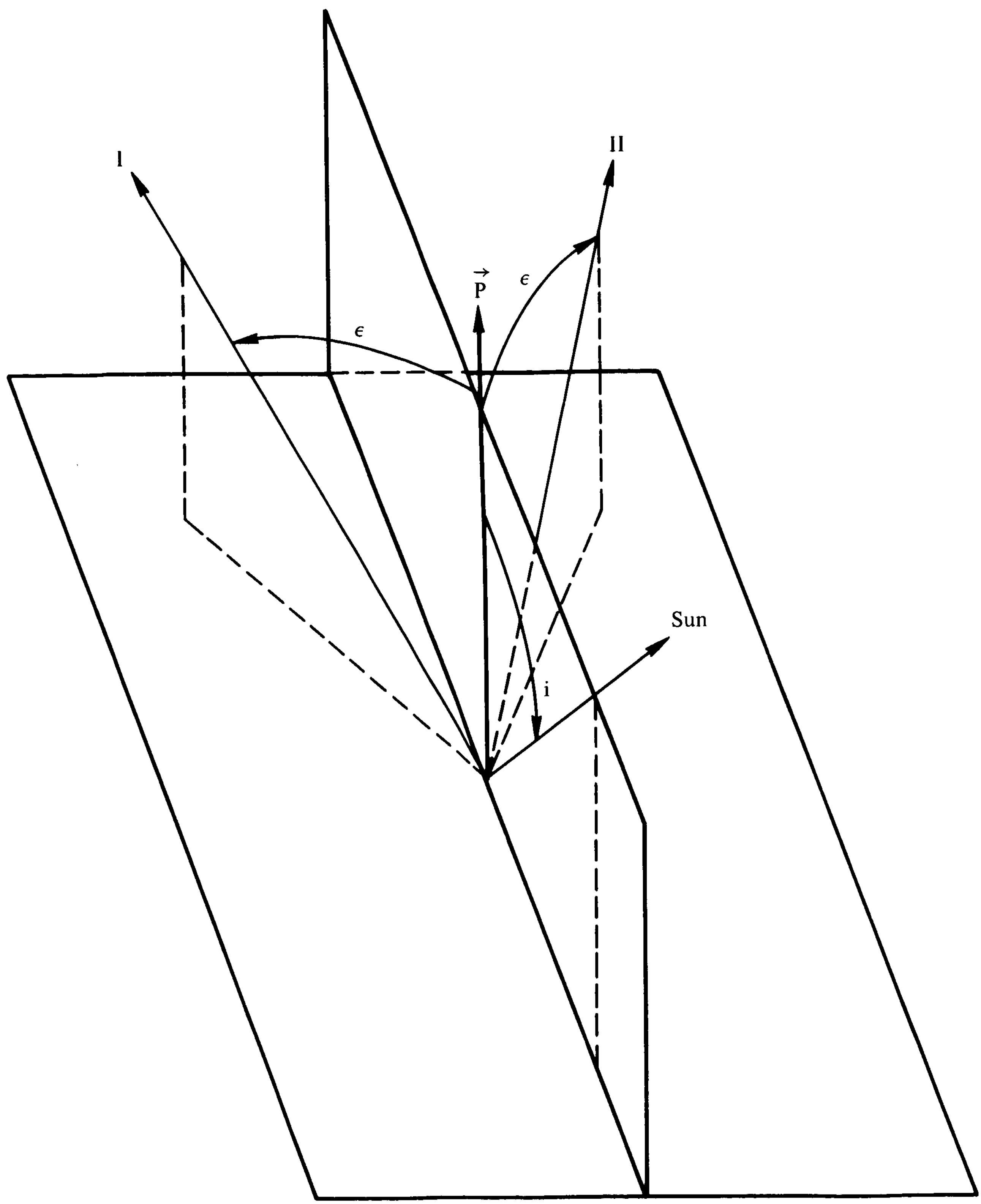


FIGURE 3 - TWO VIEWING DIRECTIONS, I AND II, THAT HAVE THE SAME ILLUMINATION GEOMETRY. THE TWO VIEWING DIRECTIONS ARE SYMMETRICALLY LOCATED WITH RESPECT TO THE PLANE THROUGH THE SUN DIRECTION AND THE LOCAL VERTICAL , $\vec{P}$

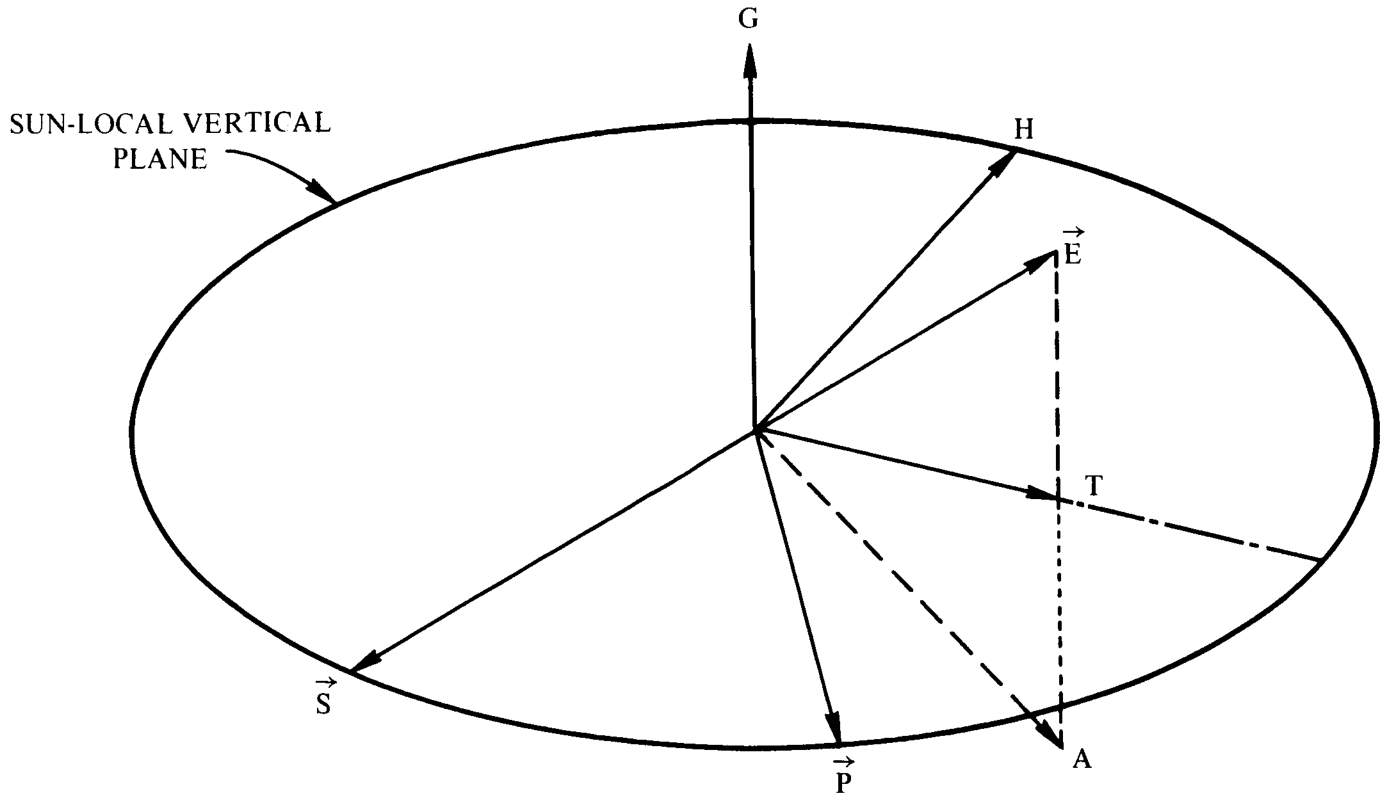


FIGURE 4 - GEOMETRY FOR CALCULATING THE VECTOR TO THE ALTERNATE VIEWING DIRECTION, $\vec{A}$. THE VECTOR $\vec{S}$ POINTS TO THE SUN, $\vec{E}$ POINTS TO THE EARTH, AND $\vec{P}$ IS THE LOCAL VERTICAL AT THE VIEWED POINTS. THE REMAINING VECTORS ARE CONSTRUCTS FOR THE CALCULATION OF $\vec{A}$

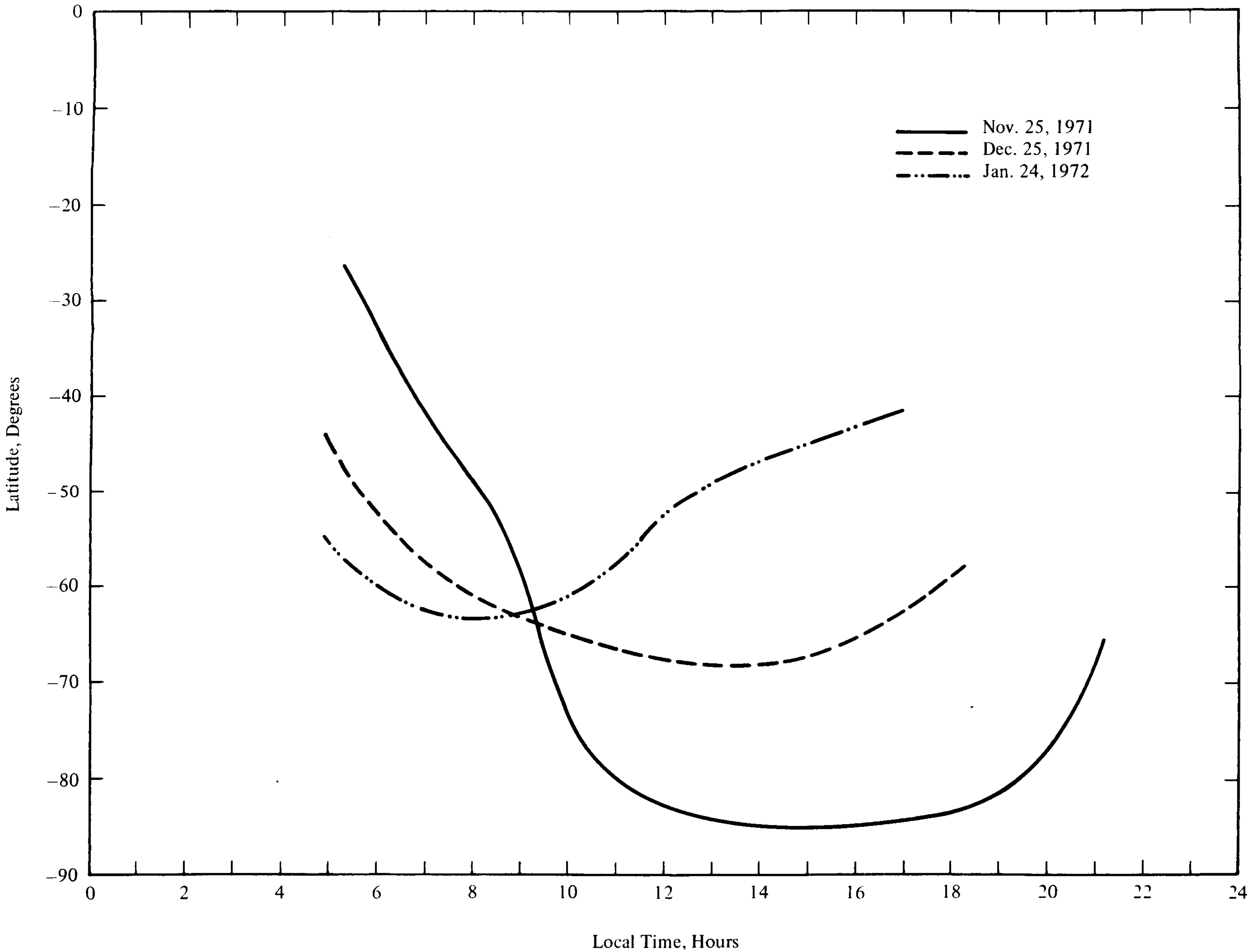


FIGURE 5 - POINTS ACCESSIBLE FOR CALIBRATION USING THE ALTERNATE GEOMETRY

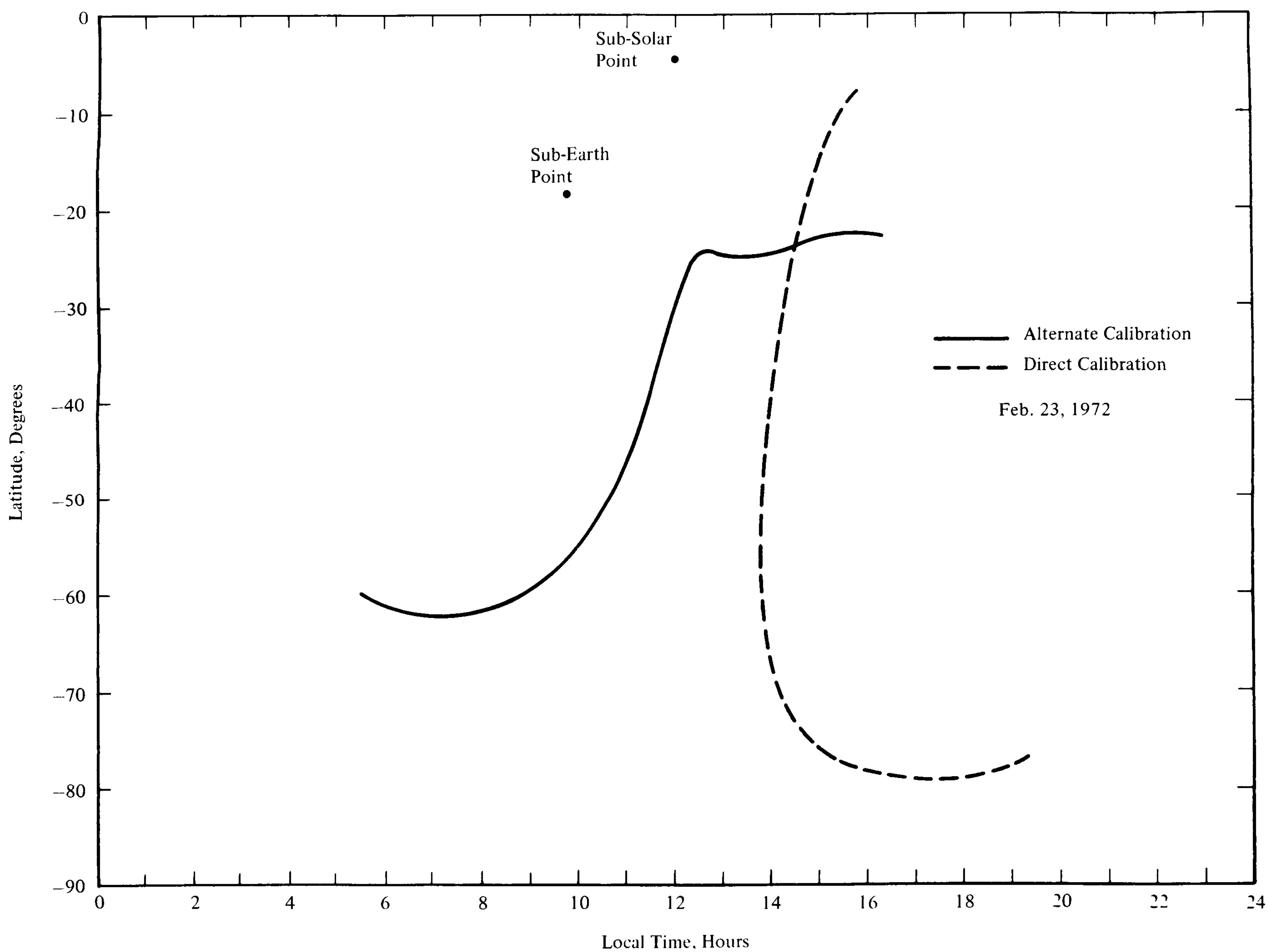


FIGURE 6 - DIRECT AND ALTERNATE CALIBRATION POINTS FOR FEB. 23, 1972

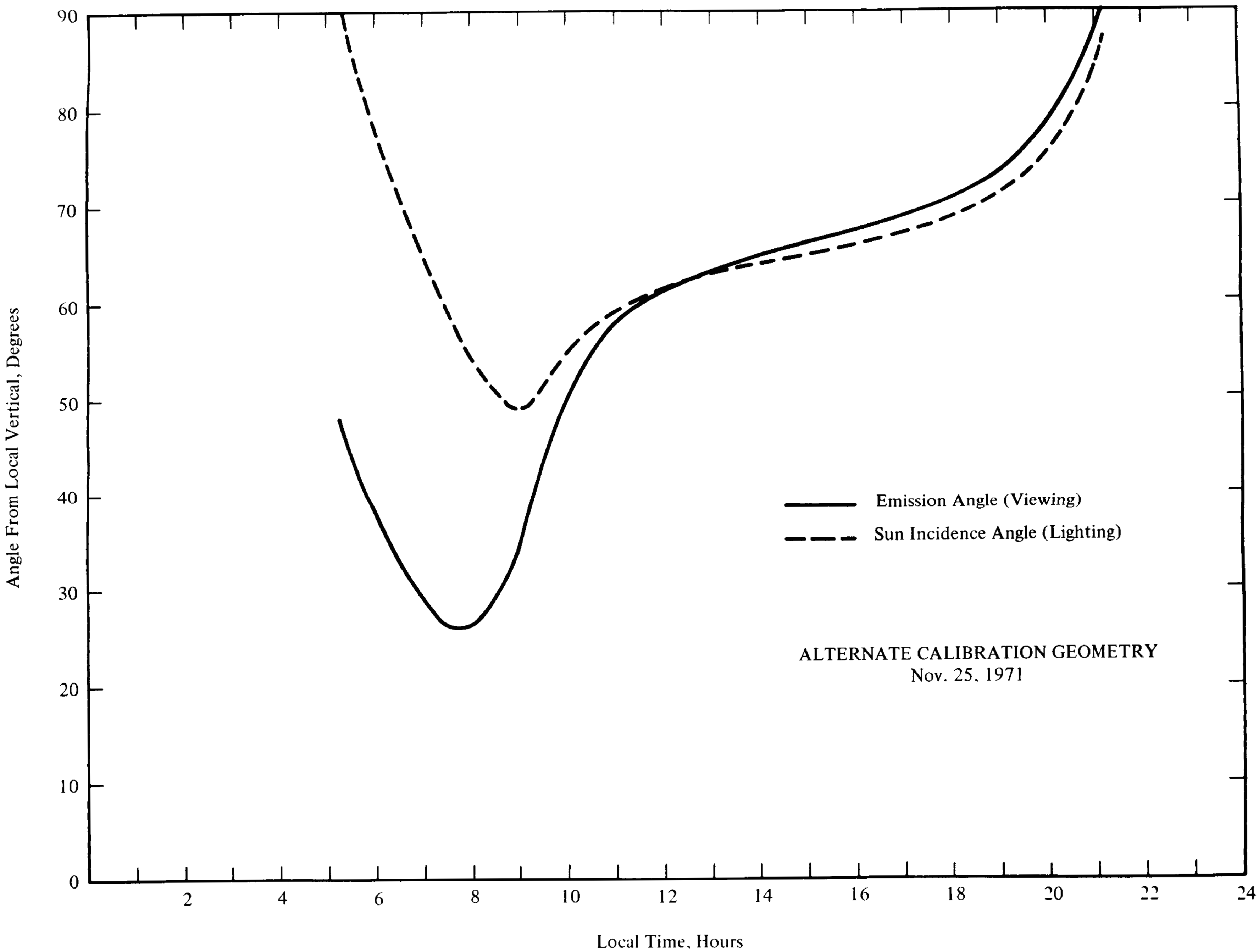


FIGURE 7 - EMISSION AND SUN INCIDENCE ANGLES FOR THE ALTERNATE CALIBRATION GEOMETRY ON NOV. 25, 1971

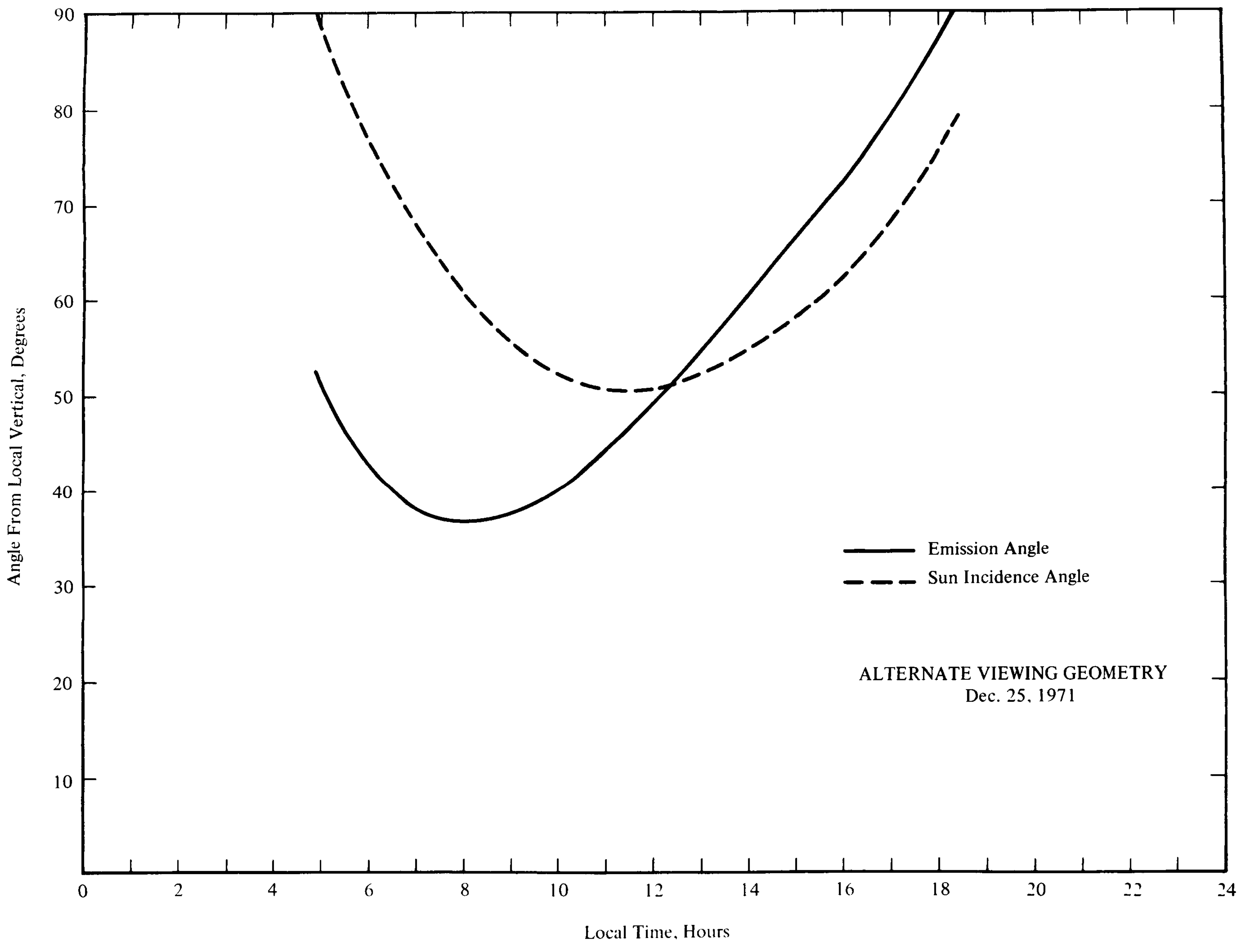


FIGURE 8 - EMISSION AND SUN INCIDENCE ANGLES FOR THE ALTERNATE CALIBRATION GEOMETRY ON DEC. 25, 1971

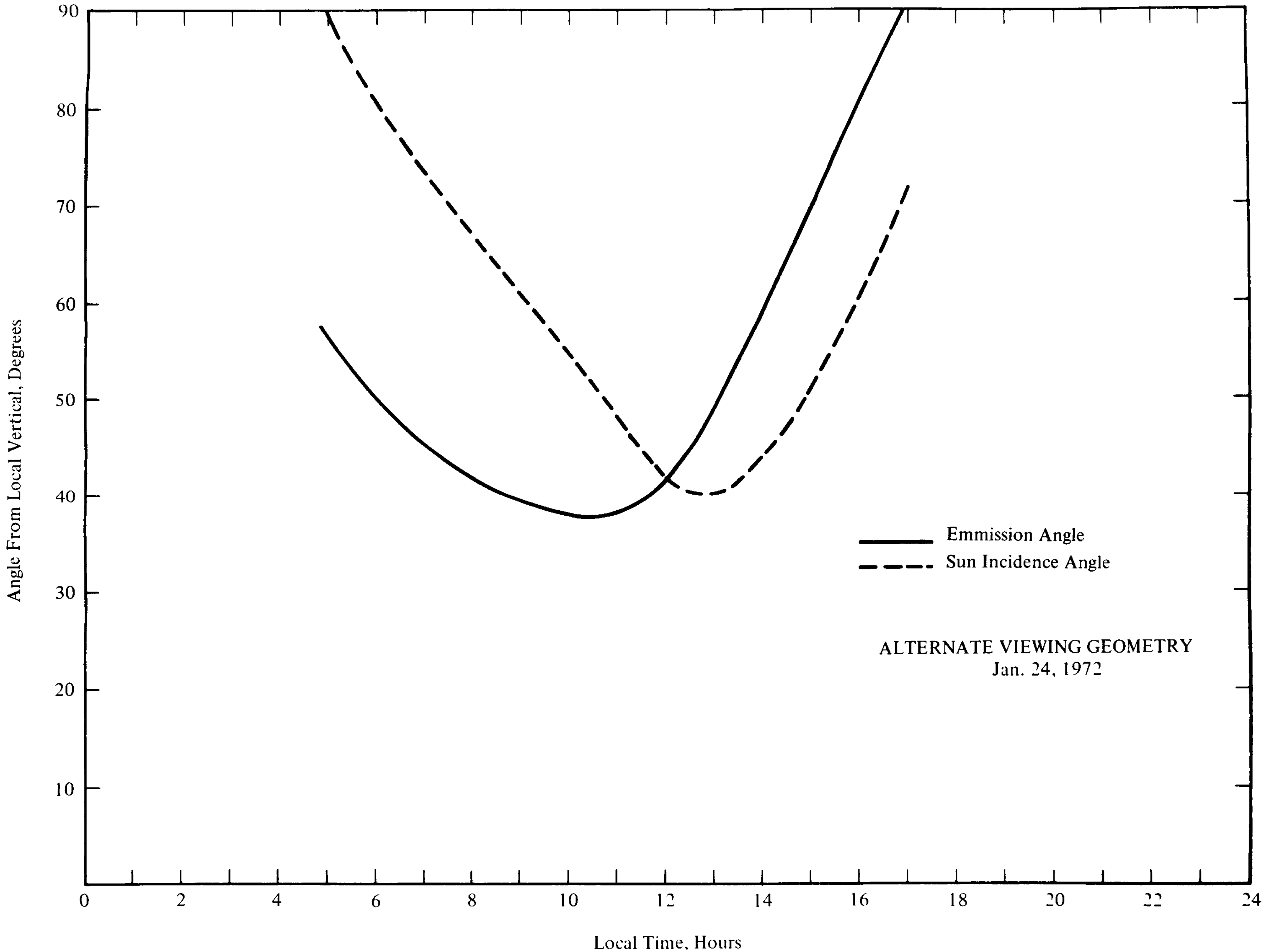


FIGURE 9 - EMISSION AND SUN INCIDENCE ANGLES FOR THE ALTERNATE CALIBRATION GEOMETRY ON JAN. 24, 1972

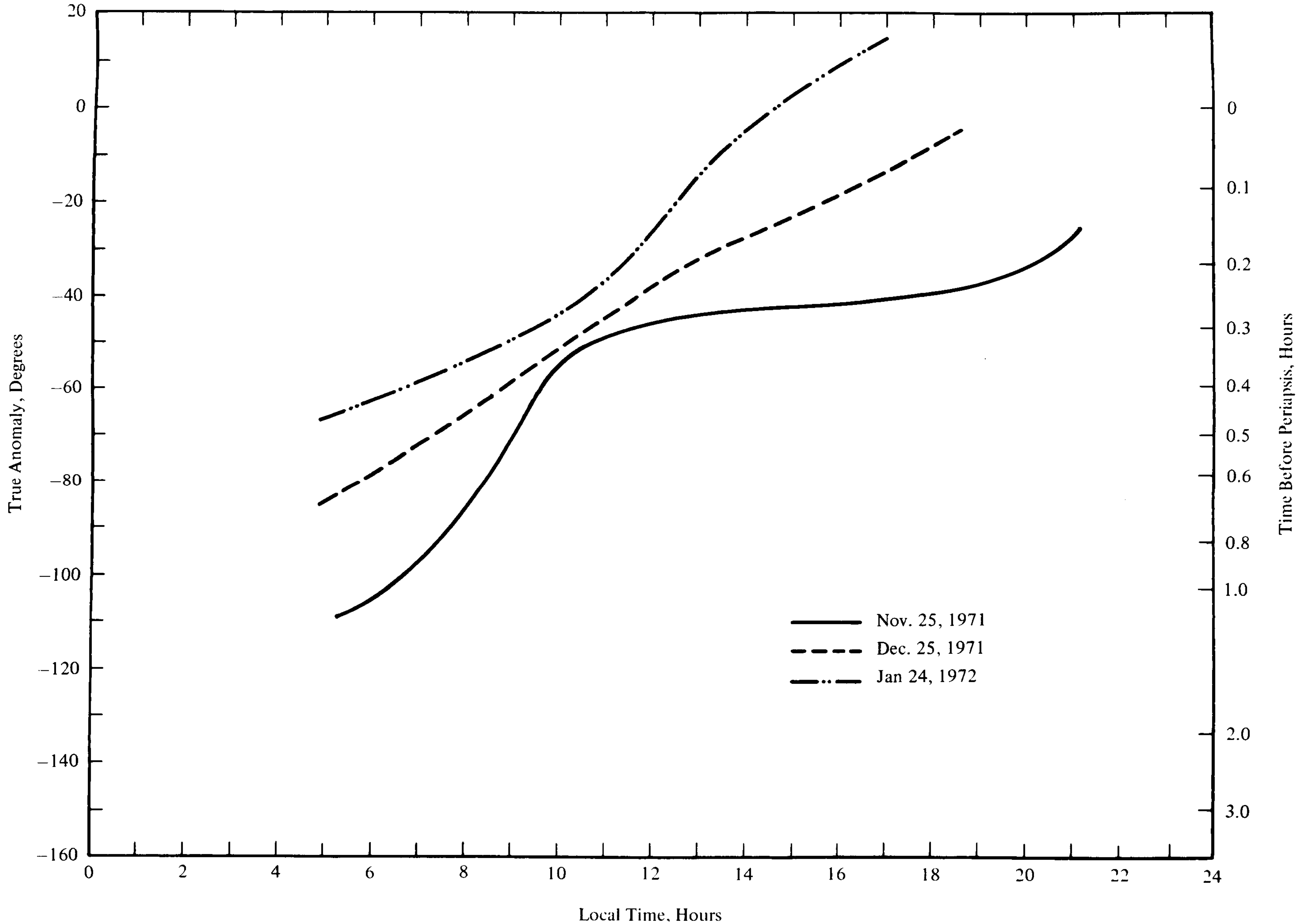


FIGURE 10 - TRUE ANOMALY AT WHICH THE ALTERNATE CALIBRATION CAN BE MADE. THE RIGHT HAND SCALE GIVES THE TIME BEFORE PERIAPSIS

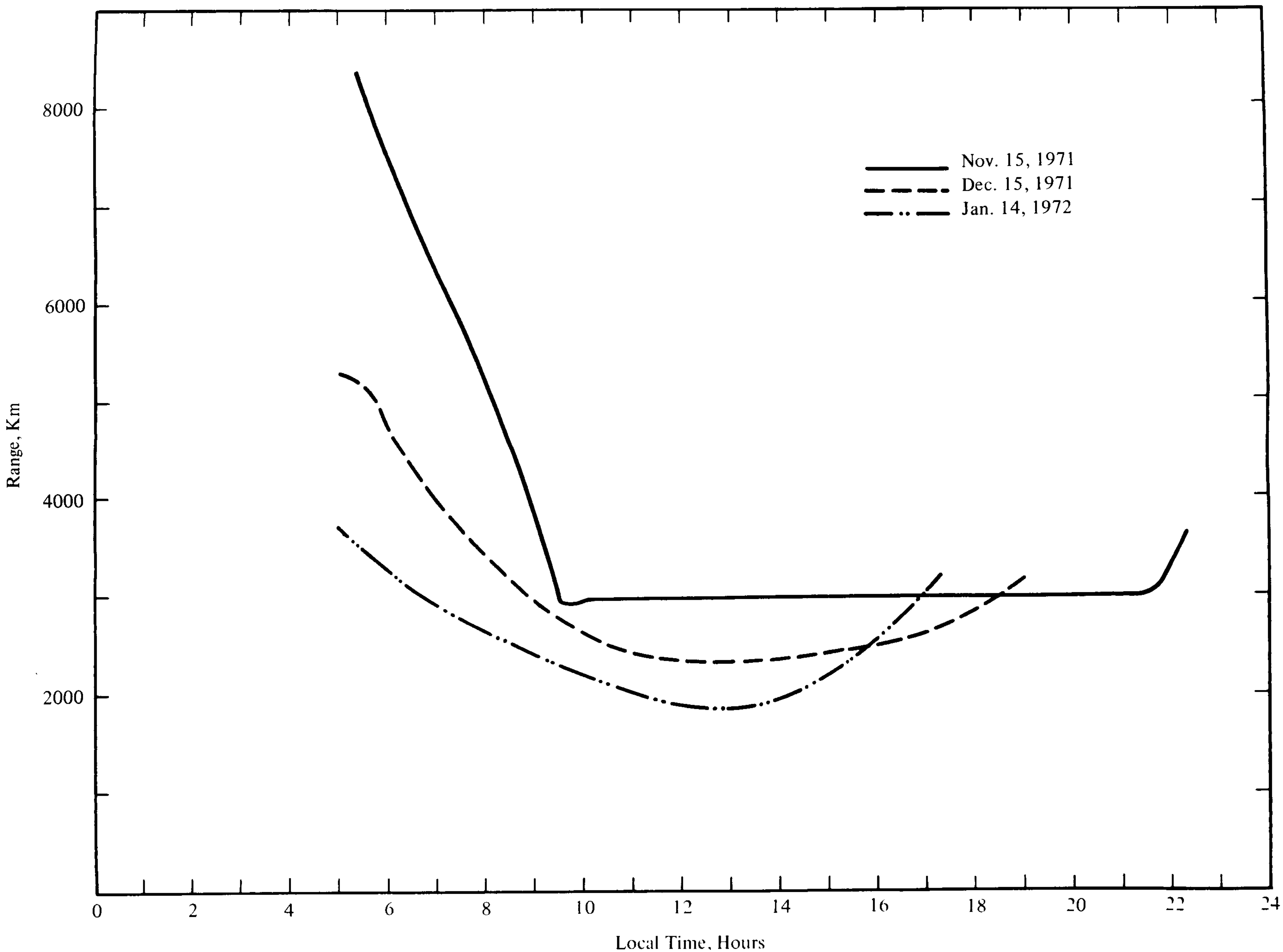


FIGURE 11 - RANGE TO ALTERNATE CALIBRATION POINTS

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